CTM simulations in the CAM framework
Phil Rasch and Peter Hess

- Initial implementation with
  - Francis Vitt, Stacy Walters (ACD)
  - Dani Bundy-Coleman (CGD)
- Next steps
  - Jean Francios LaMarque
  - Natalie Mahowald

- Collaborative effort between
  - Climate and Global Dynamics Division
  - Atmospheric Chemistry Division
  - CCSM

CAM3

- CAM = Community atmosphere Model
  - Descendant of CCM3
  - A general circulation model
  - Successfully used for reanalysis, data assimilation
  - A component of CCSM3.0 (Community Climate System Model)
    - Physical components, land (CLM), ocean (POP), sea ice (CSIM)
    - Biophysical components
      - CSIM non-dynamic-vegetation PFTs compete for light and water, act as sources and sinks for water, heat, CO2, NVOC
      - Dynamic vegetation model optional
    - Chemistry
      - Troposphere mechanism (MOZART, JF)
      - Middle atmosphere mechanism (MOZART,WACCM, DK)

Goals

- Add offline transport model functionality to CAM/CCSM
- Phase out of MATCH & MOZART as their functionality is replaced

Motivation

- Reduce software engineering burden
- Add opportunities for new science with CAM/CCSM

Software engineering issues

- Coding can be done for offline/online once
- Input and output datasets uniform
- Large number of people (scientists and SE) looking at, developing the code
- Migration to revised models done more easily with source code maintainance tools
- Distribution to the outside world handled more easily

New Science

- Compare with measured quantities for real episodes.
- Allow feedbacks with climate with no recoding
- Much more comprehensive and consistent land model (physics and biogeochemistry)
  - Deposition, mobilization, VOCs, etc.
- New functionality for "Climate System Modeling"
  - Interactive ocean, sea ice, land.
  - Prescribed meteorological atmosphere
    - Constituents can evolve and provide "information conduit" between other components
- Automatic connection to data assimilation, and forecasting
  - DART (Data Assimilation Research Testbed)

Transport processes in model

- Dynamics and Transport
  - 3 Dynamical Cores
    - 3 spectral resolutions (higher resolutions being planned)

Dynamics	Transport
Spectral Eulerian	Semi-Lagrangian
Semi-Lagrangian	Semi-Lagranian
Finite Volume	Finite Volume

  - Boundary Layer parameterization follows Holtslag and Boville
  - Shallow convection scheme follows Hack
  - Deep convection follows Zhang and McFarlane

Offline capability only present with FV core

- Input files are always netCDF files
  - Met fields typically at 3 hr intervals
  - Pressure, temperature, winds, surface fluxes
- Model has been run with meteorology from
  - CAM3
  - NCEP
  - ECMWF
- Essentially whole GCM is run, resetting meteorology to prescribed met fields every timestep – kind of expensive for few tracers, cheap for many
- Like MATCH/MOZART Hydrologic Cycle and convection is always "predicted"

First Stage

- Two suites of tracers were employed
  - Low, Medium, High and "Inverse Medium", Unit (30 days)
  - Radon, Pseudo-Ozone, SF6, Neutral Biosphere Tracers (10 years)
  - NB sources from CASA (Randerson et al)
    - Monthly mean NB (seasonal rectification)
    - Diurnally varying NB (seasonal+daily rectification)
    - Shifted diurnal phase NB (sensititivity to errors in parameterization phase error)
- Each suite was run in offline CAM with different met fields
- Compared with Online-CAM, MOZART and MATCH

Second Stage

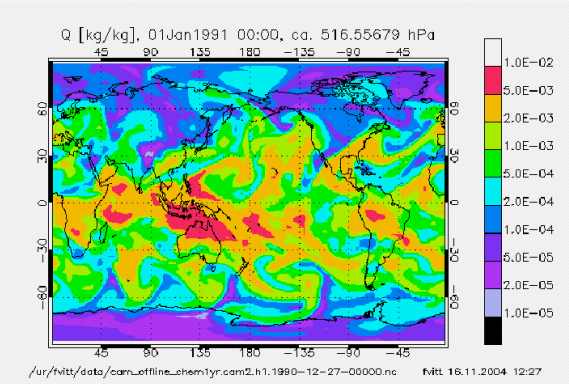
- Online photochemical mechanism from JF
- 96 (gas and aerosol) species
- Compare CAM-online/CAM-offline simulations with CAM meteorology fields
  - Run for 1 year, look at fields on last day of year
- Compare CAM-offline CAM met fields to CAM-offline with NCEP fields
- Compare CAM-offline with NCEP reanalysis to MOZART-offline with NCEP reanalysis

Compare water vapor offline/online (about 500 mb)

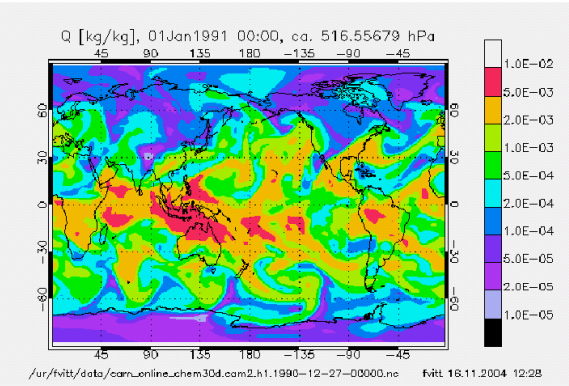
Zonal Avg

Water Vapor @ 500 mbar

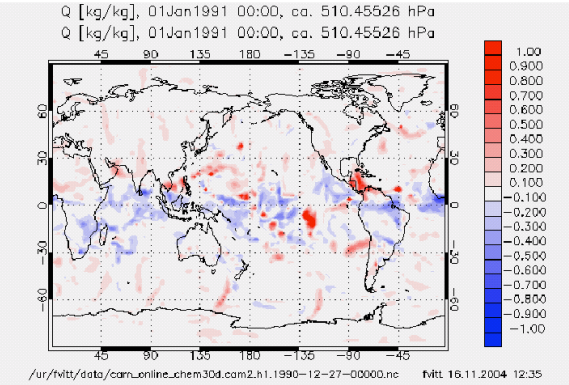
Offline CAM



Online CAM

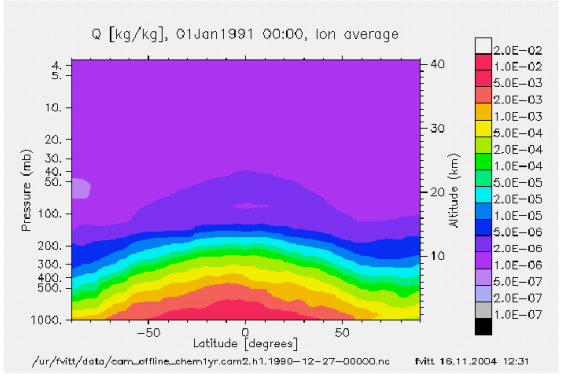


Rel Diff

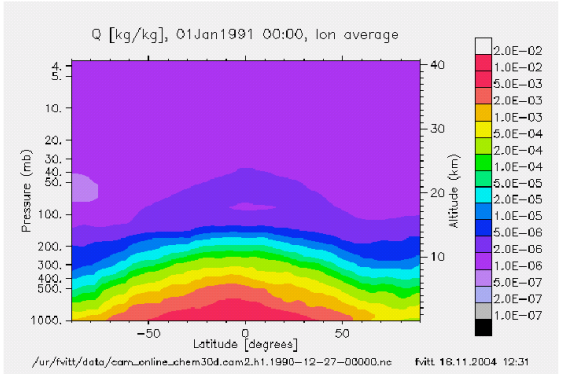


Water Vapor @ Zonal Ave

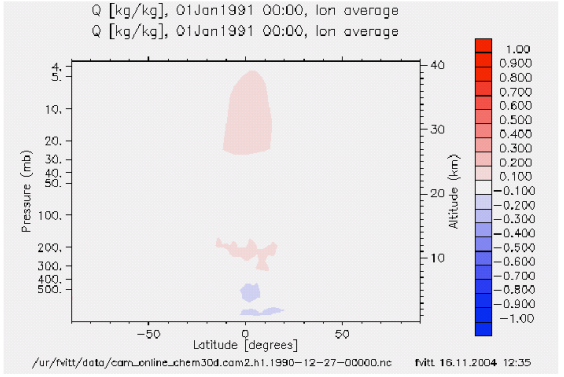
Offline CAM



Online CAM



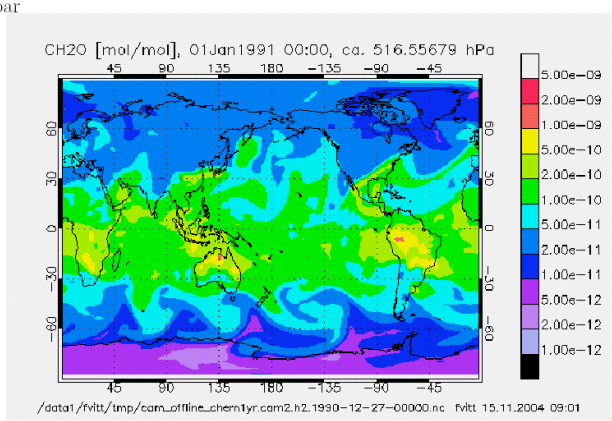
Rel Diff



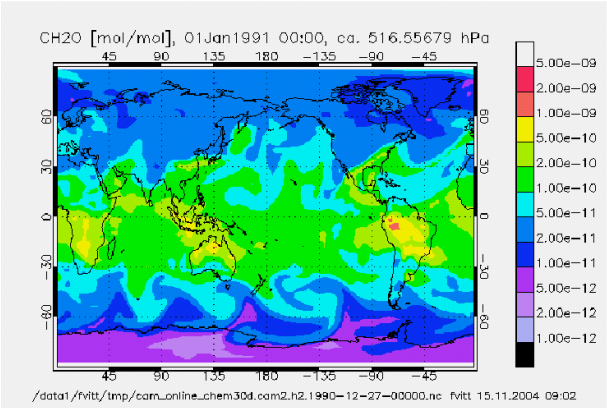
Formaldehyde

CH2O at 500 mbar

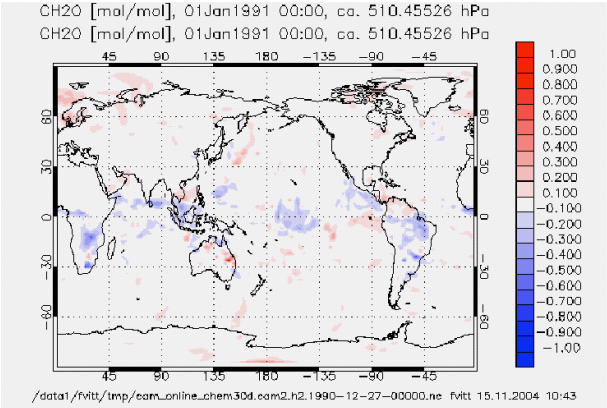
Offline CAM



Online CAM

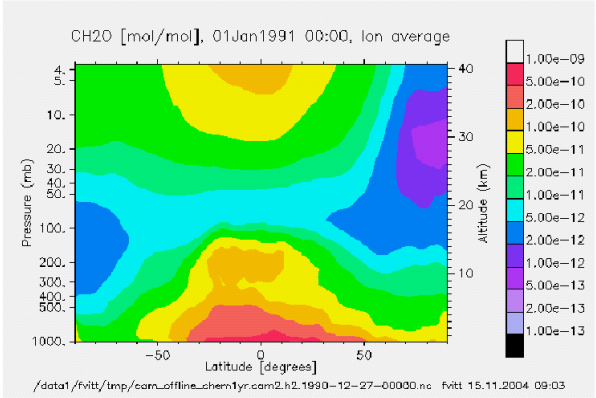


Rel Diff

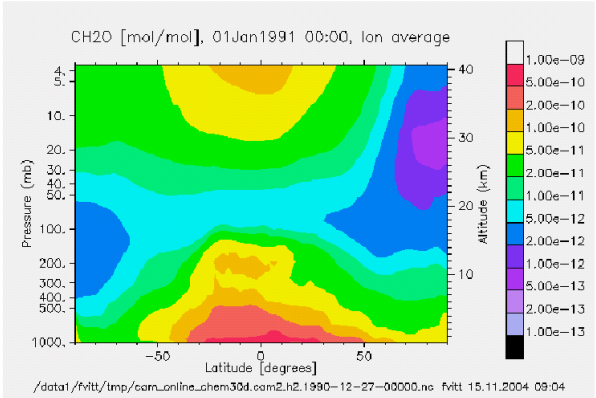


CH2O zonal average

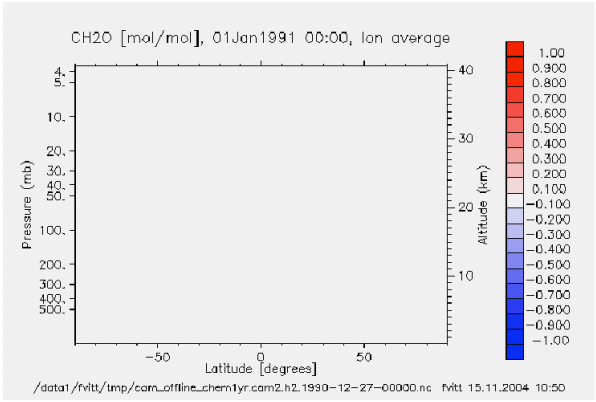
Offline CAM



Online CAM



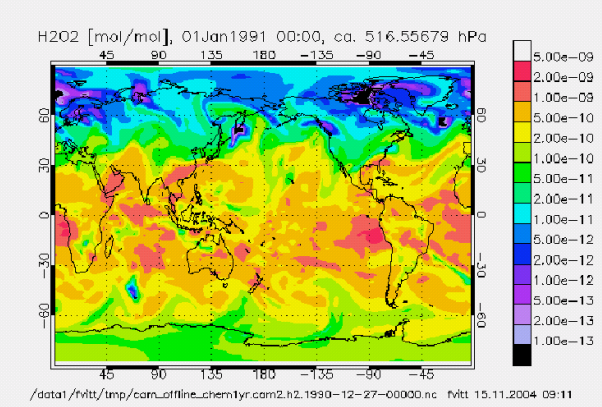
Rel Diff



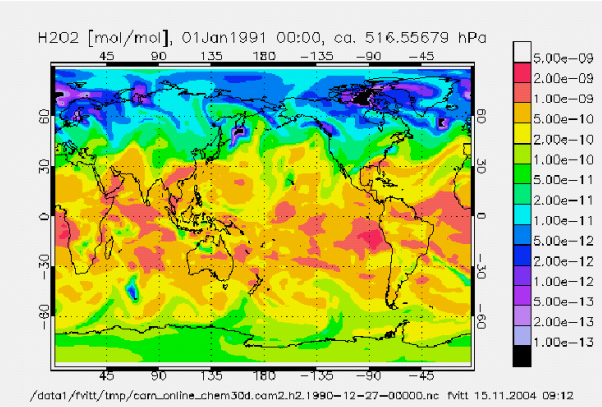
Hydrogen Peroxide

H2O2 at 500 mbar

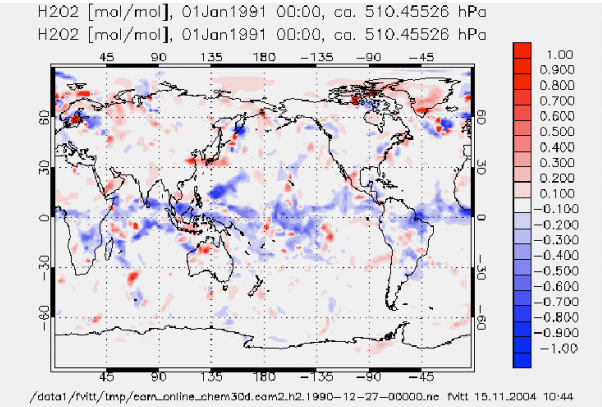
Offline CAM



Online CAM

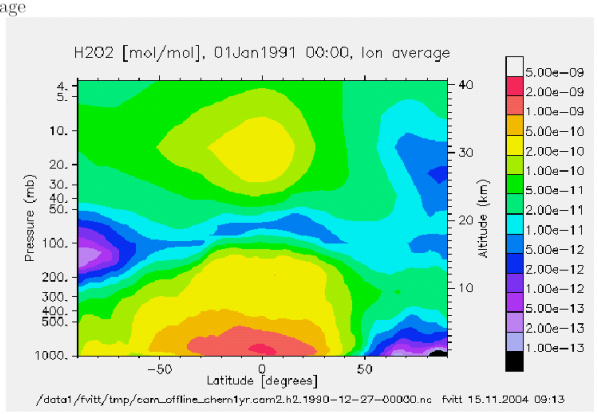


Rel Diff

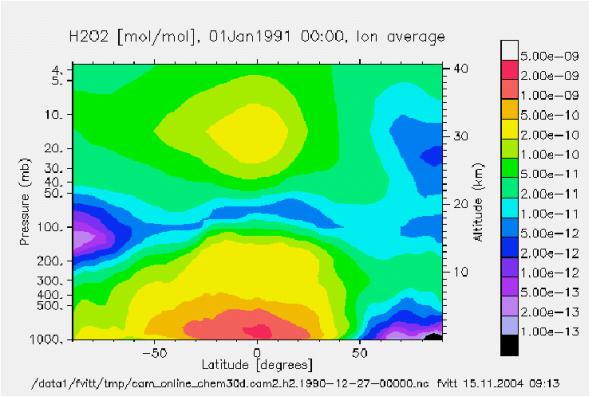


H2O2 zonal average

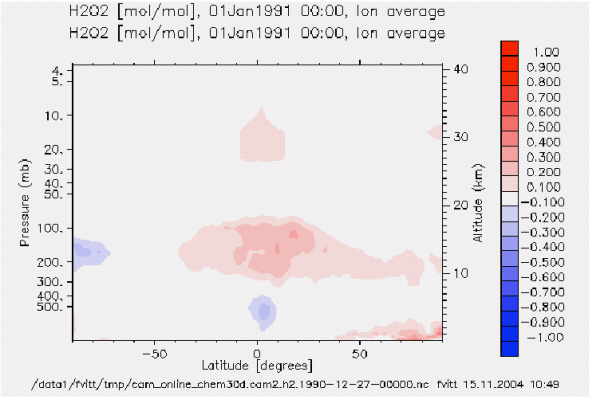
Offline CAM



Online CAM



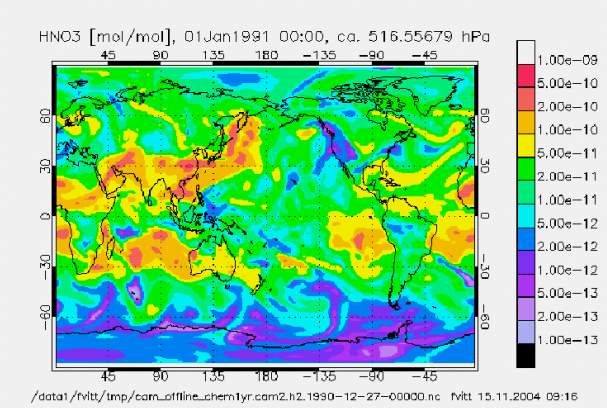
Rel Diff



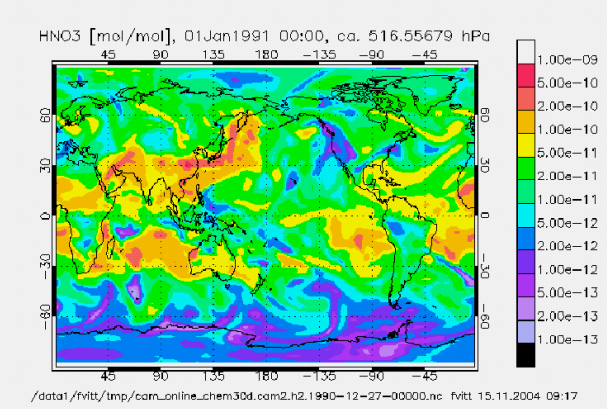
HNO3

HNO3 at 500 mbar

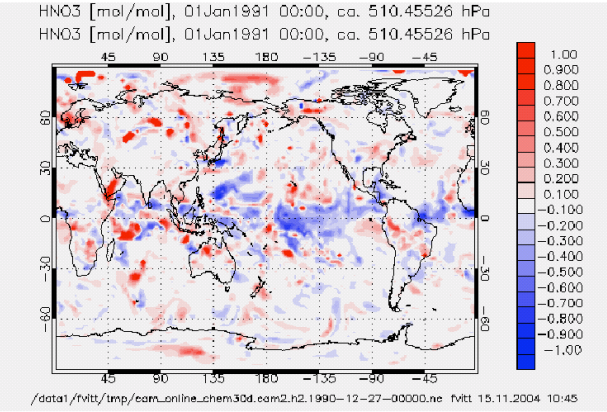
Offline CAM



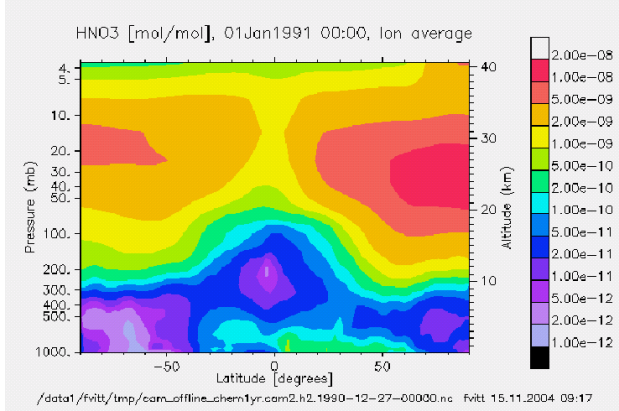
Online CAM



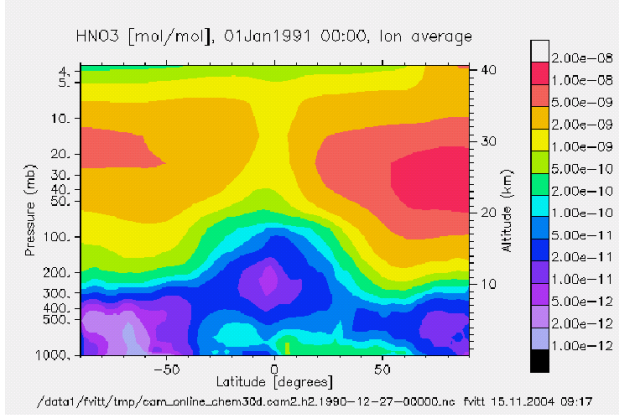
Rel Diff



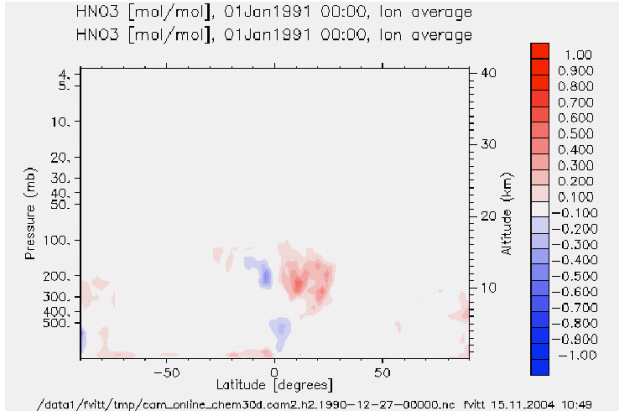
Offline CAM



Online CAM

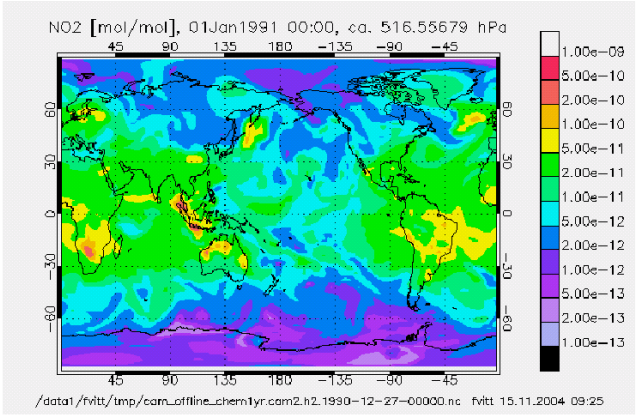


Rel Diff

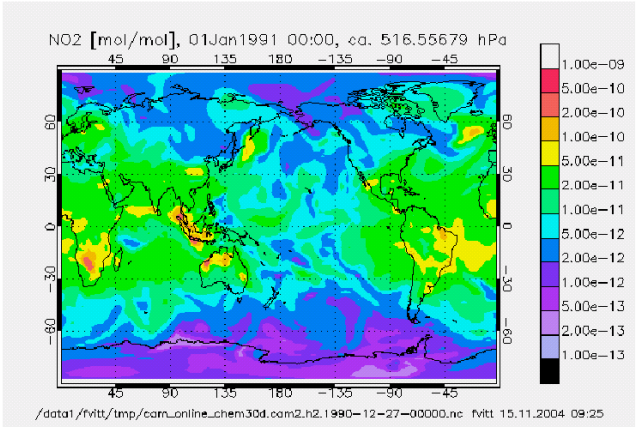


NO2

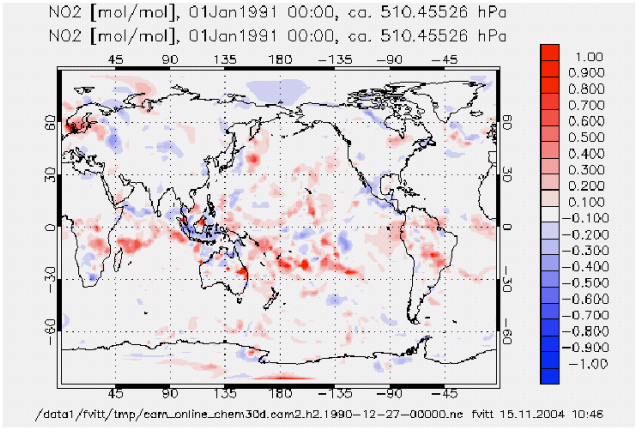
Offline CAM



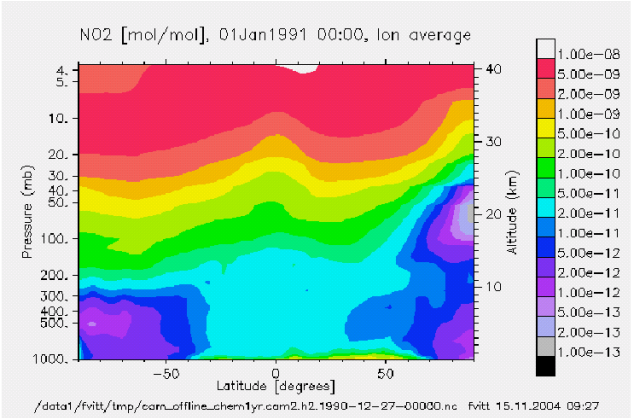
Online CAM



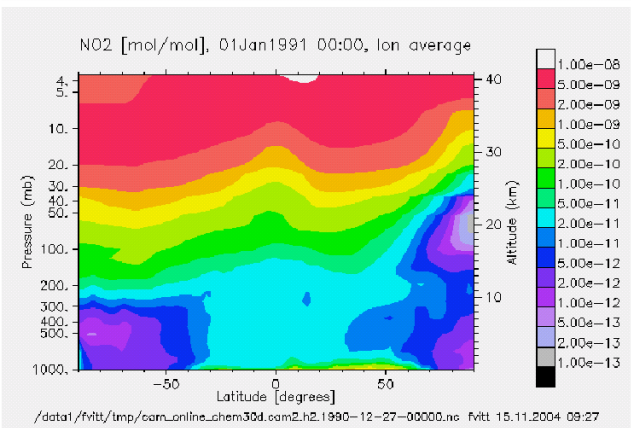
Rel Diff



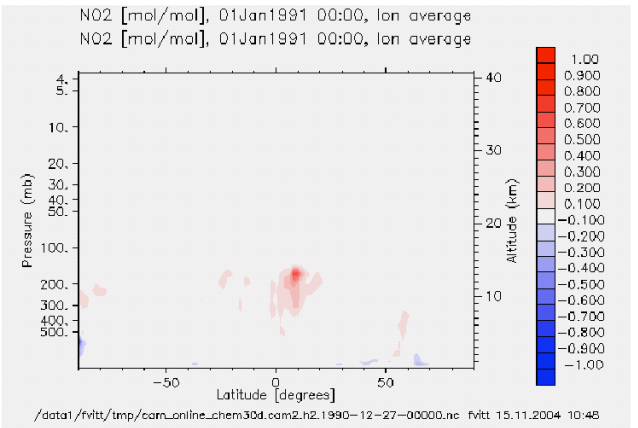
Offline CAM



Online CAM

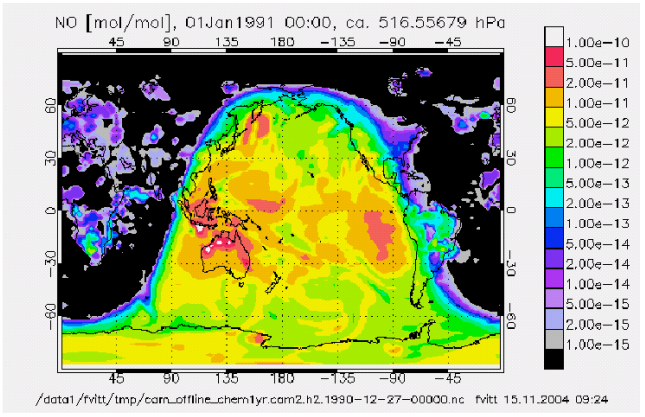


Rel Diff

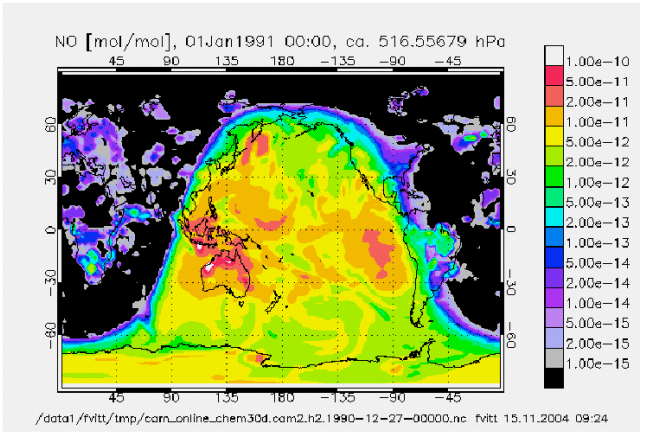


NO

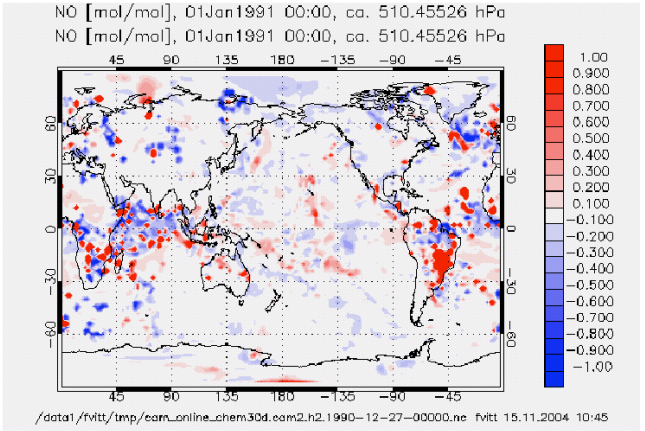
Offline CAM



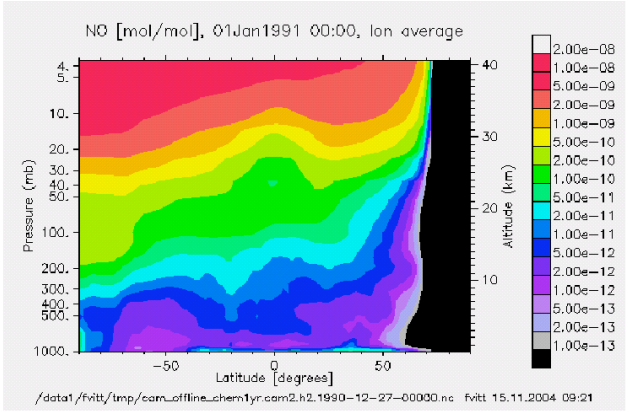
Online CAM



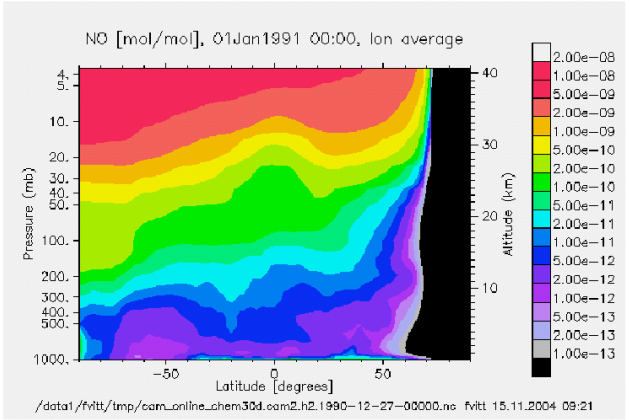
Rel Diff



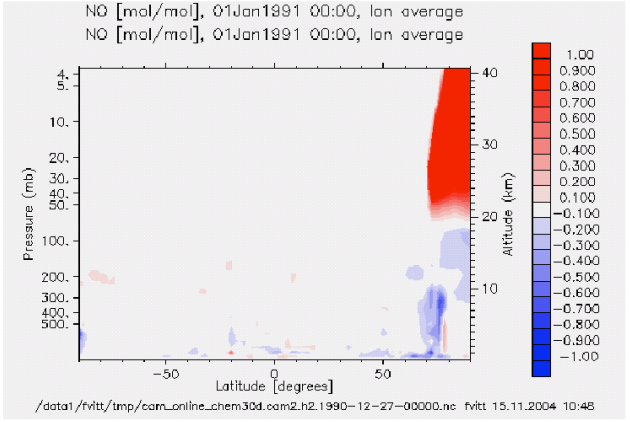
Offline CAM



Online CAM

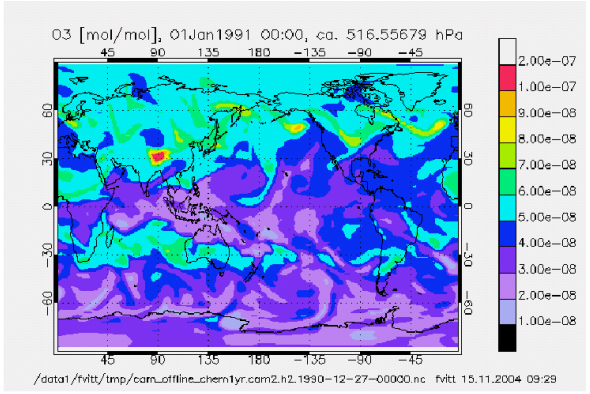


Rel Diff

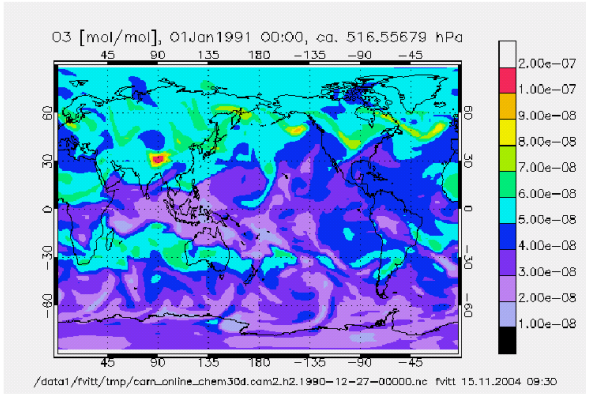


O3

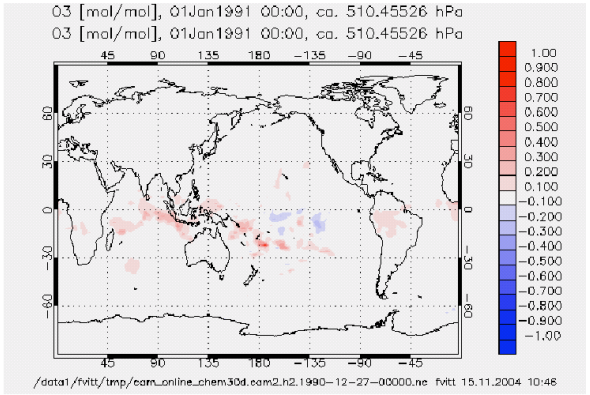
Offline CAM



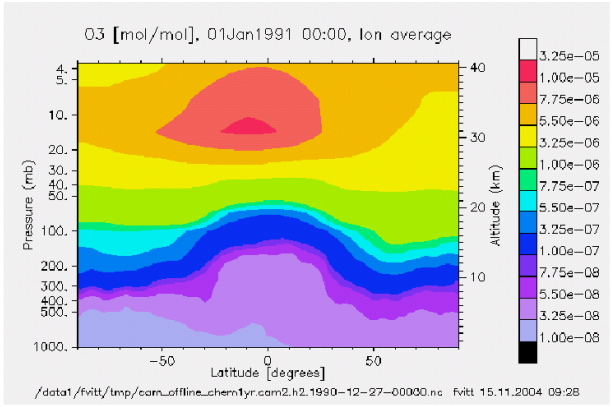
Online CAM



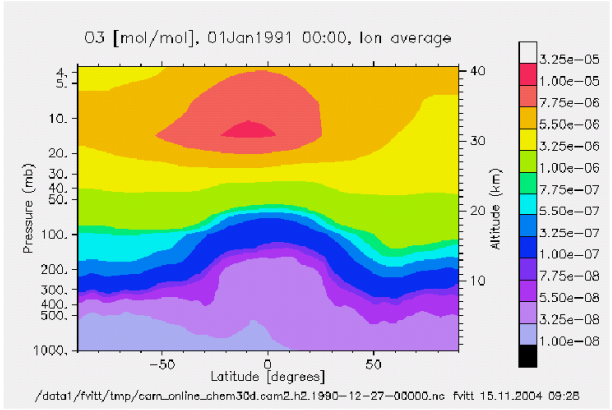
Rel Diff



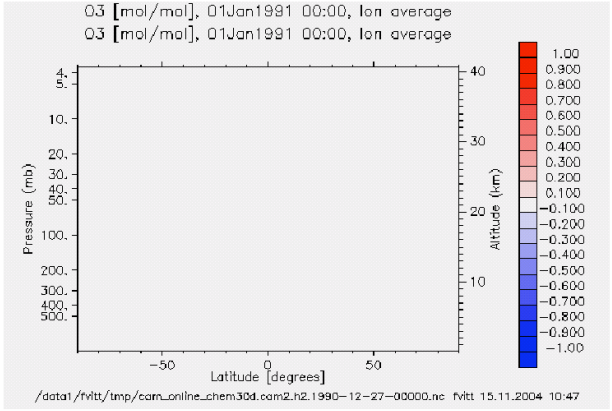
Offline CAM



Online CAM

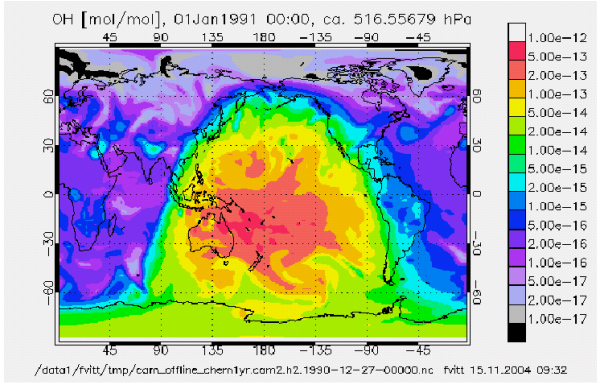


Rel Diff

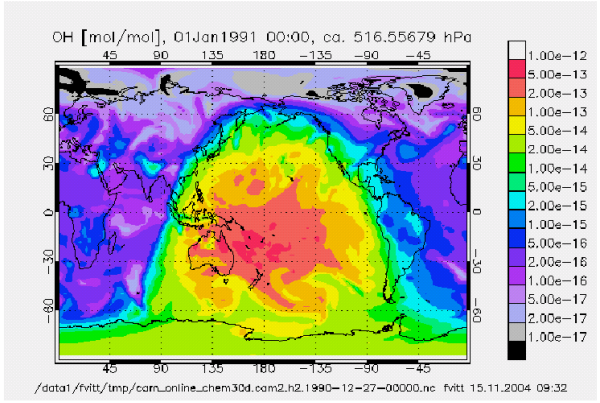


OH

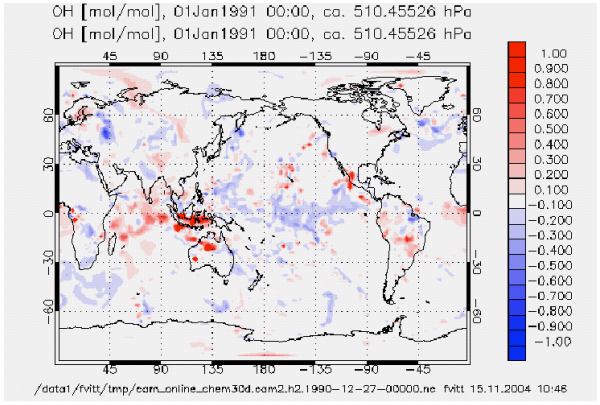
Offline CAM



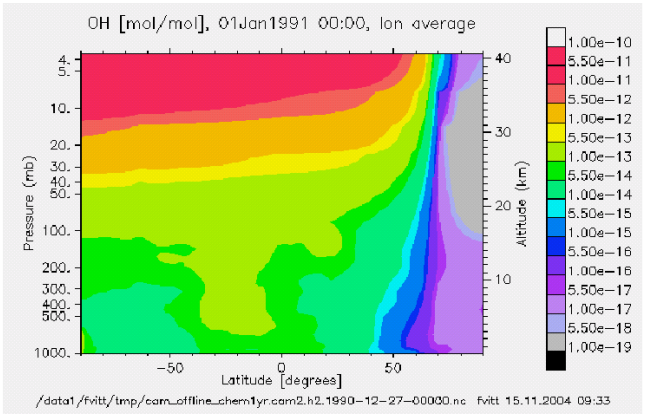
Online CAM



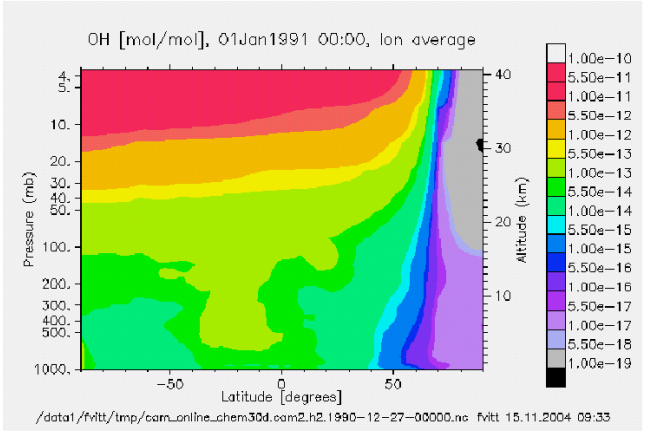
Rel Diff



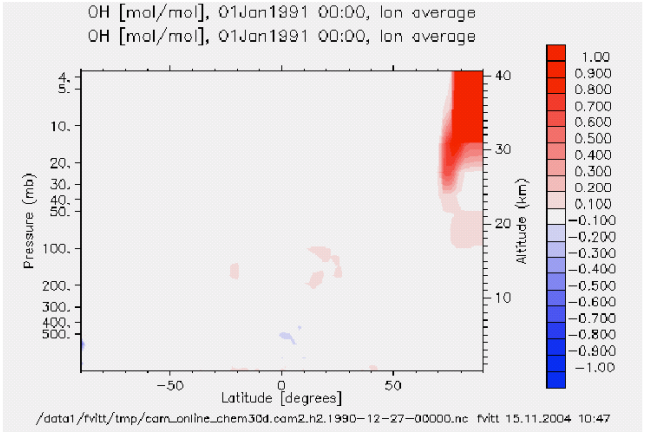
Offline CAM



Online CAM



Rel Diff



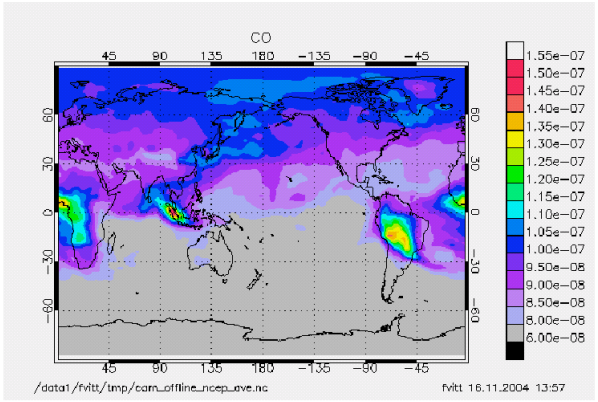
First run of Stage 2 (NCEP reanalysis)

- Both models initialized on Jan 1 1990
- Average first 30 days of simulation

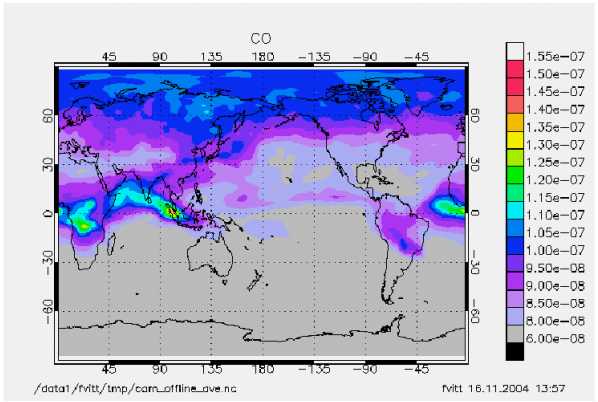
CO

CO 500 mbar

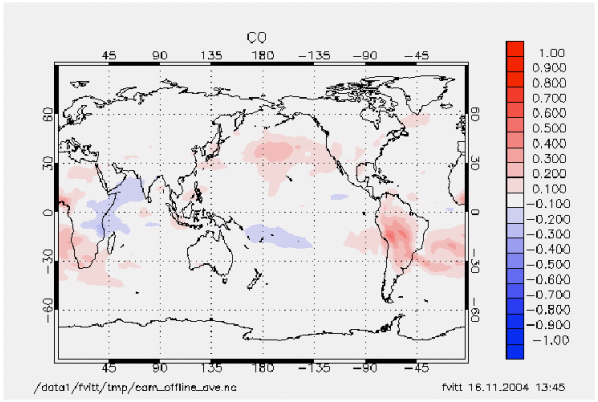
NCEP Met



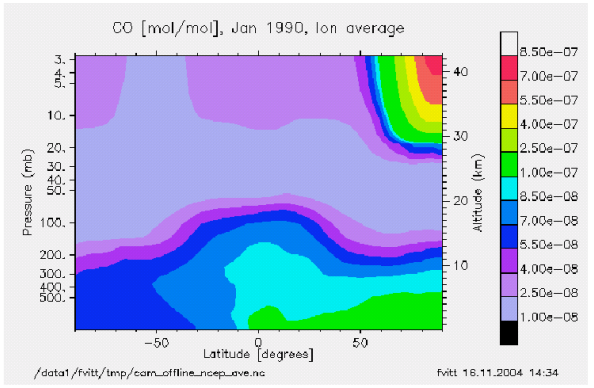
CAM MET



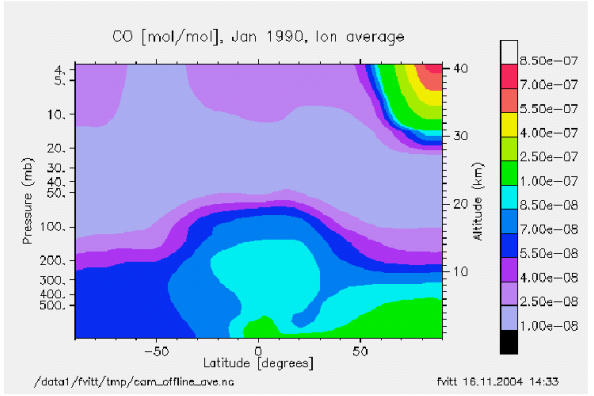
Rel Diff



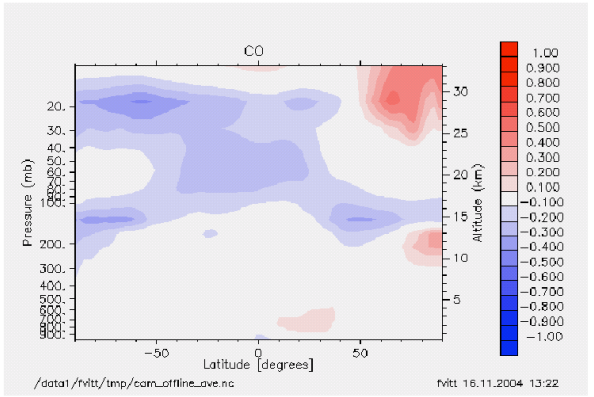
NCEP Met



CAM MET



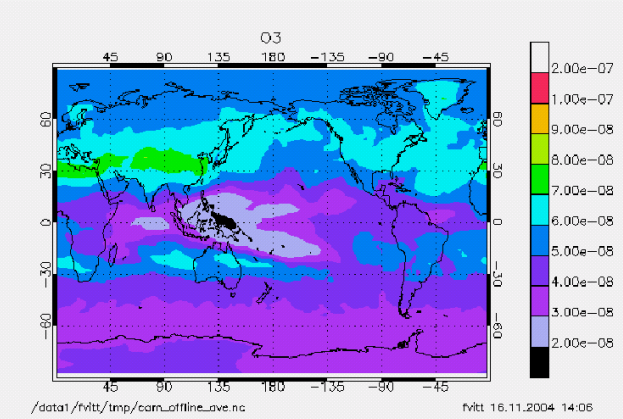
Rel Diff



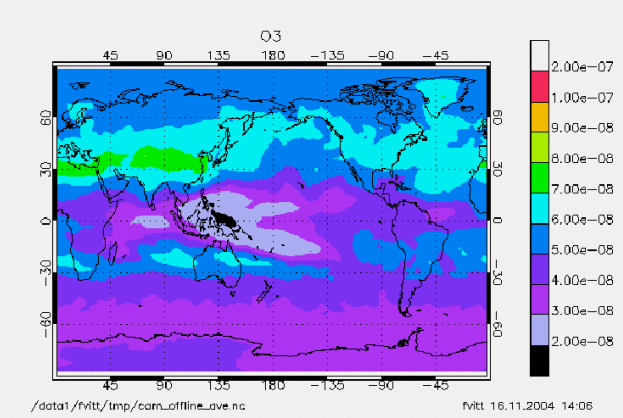
O3

O3 500 mbar

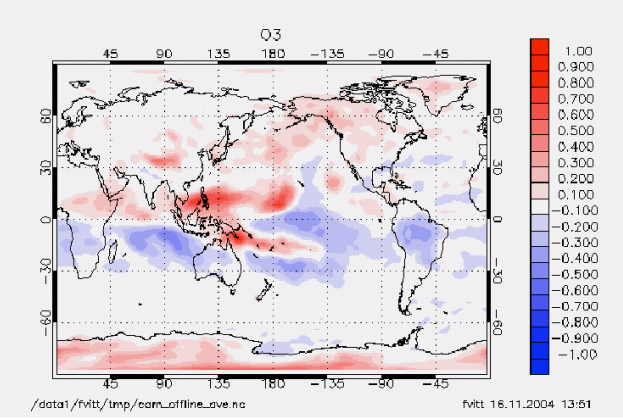
NCEP Met



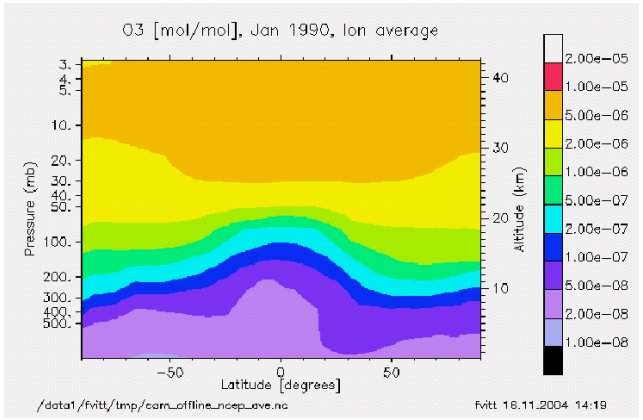
CAM Met



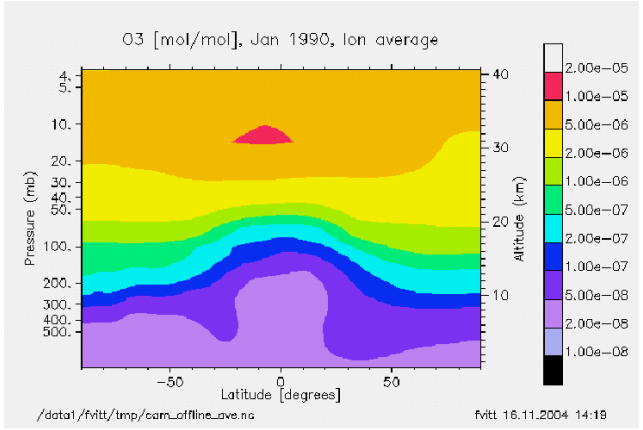
Rel Diff



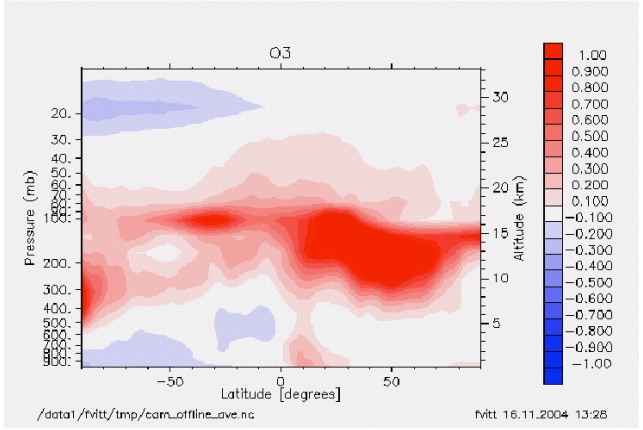
NCEP Met



CAM Met



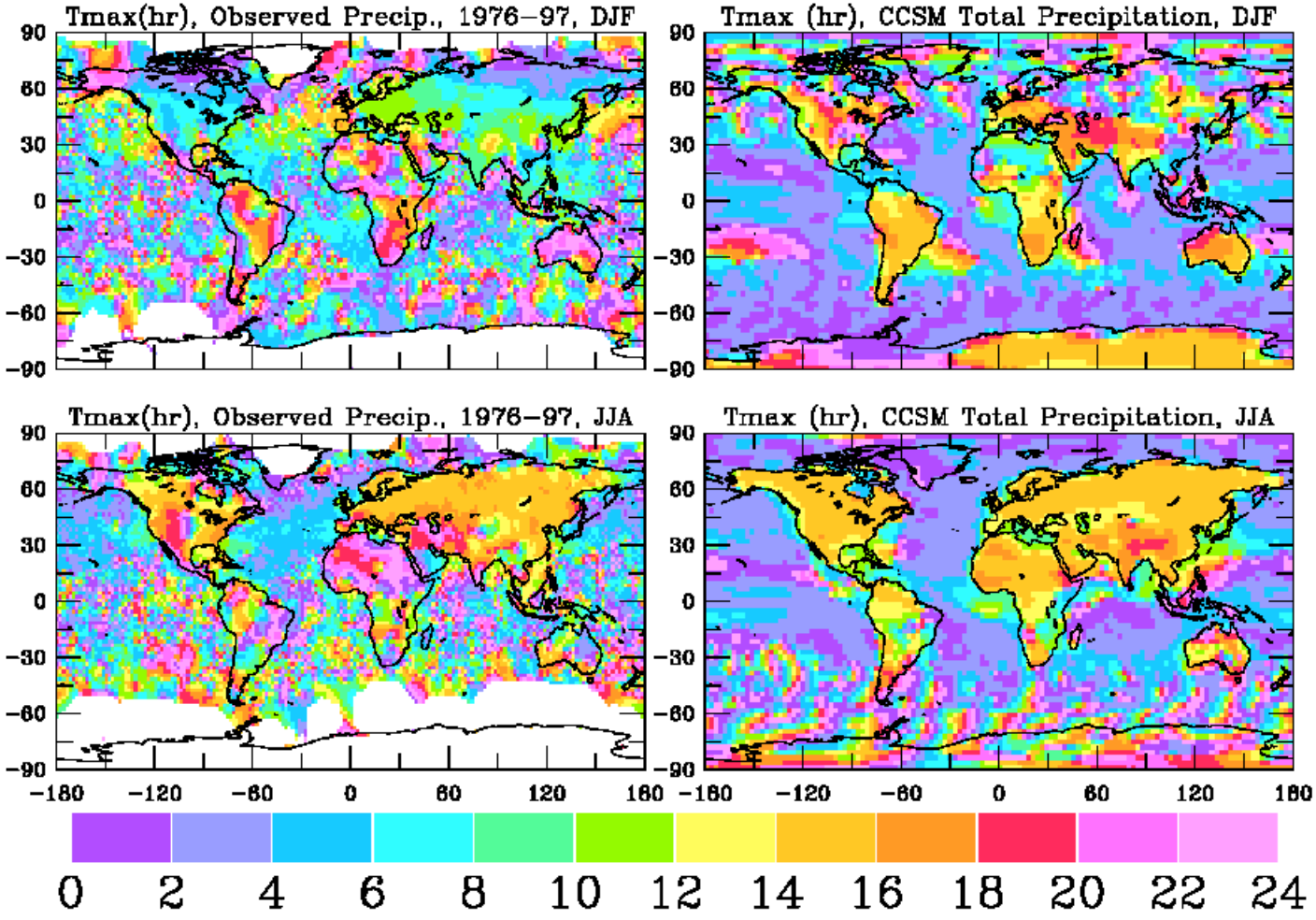
Rel Diff



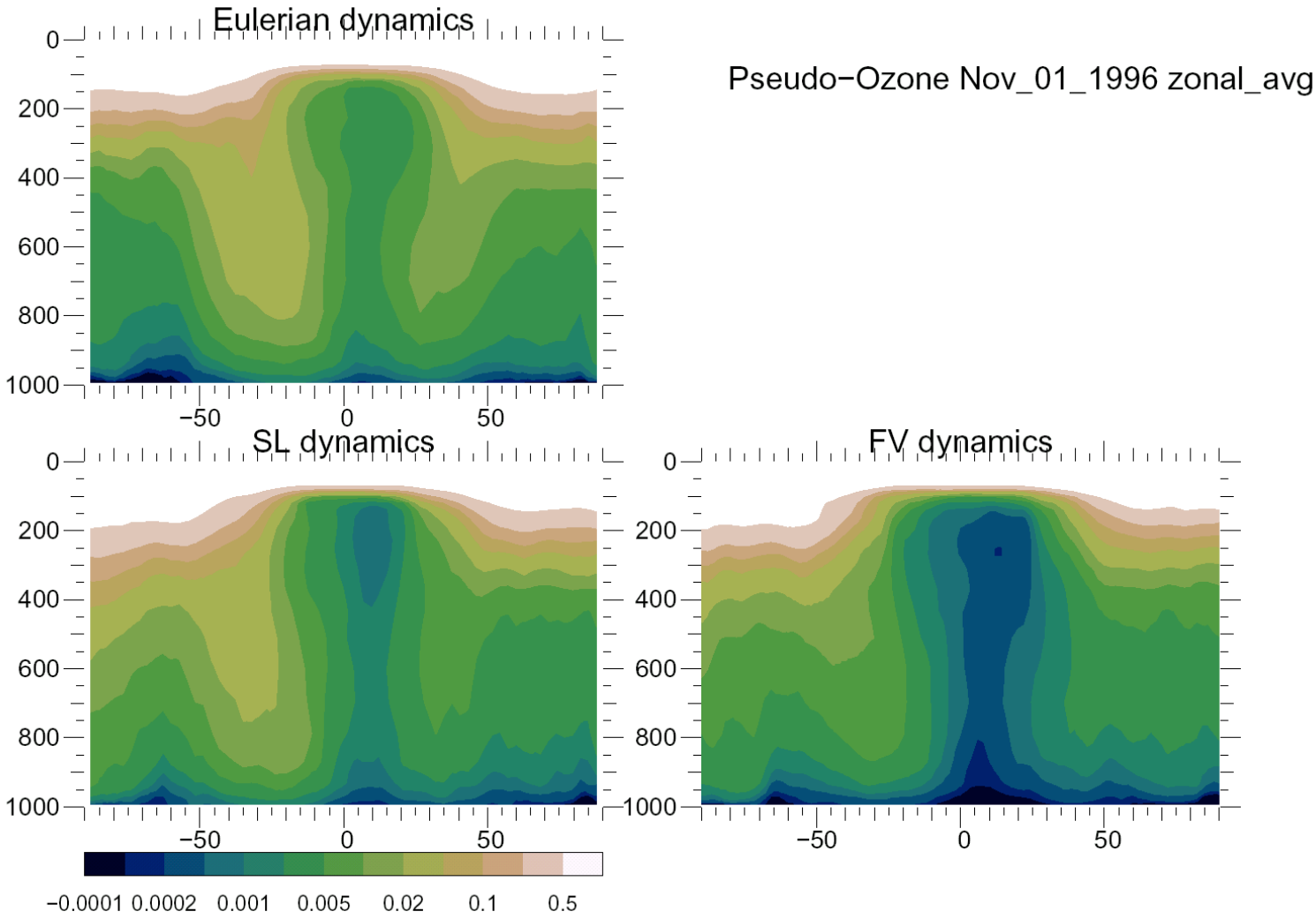
Where we are:

- More careful assessment of differing met fields
- First simulations with CGD aerosol suite
  - Bulk aerosol formulation
  - Dust (4 bins), sea salt (4bins), BC, OC, sulfate
  - Integrate with MOZART oxidants
  - Evaluation against MATCH
- Careful integration/evaluation with JF and rest of MOZART group against MOZART and online CAM
- Commit to source repository next week
- Release to community perhaps by summer 2005

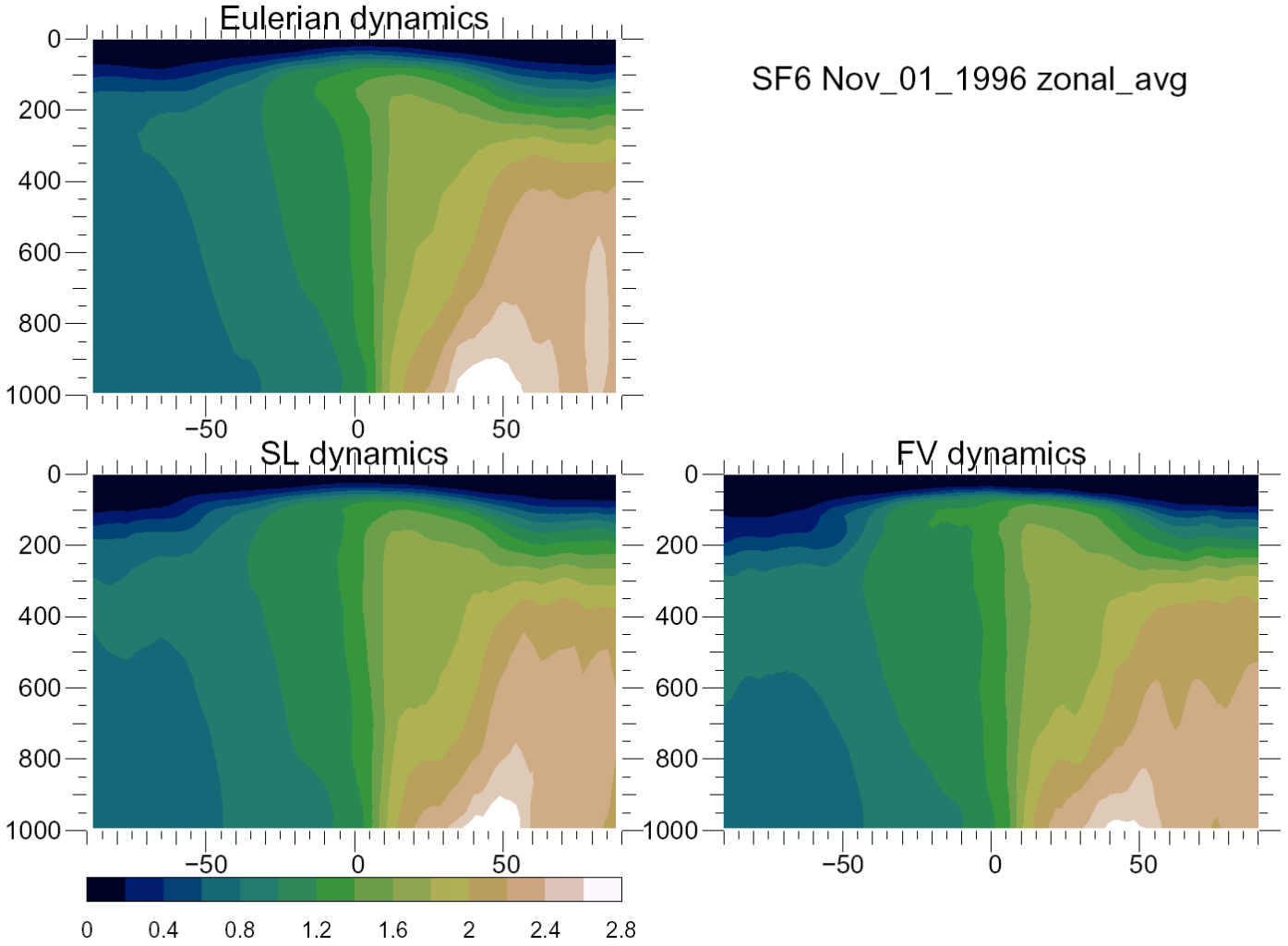
Local Hour of Max in Precipitation
(Dai et al, 2004)
Upper DJF
Lower JJA



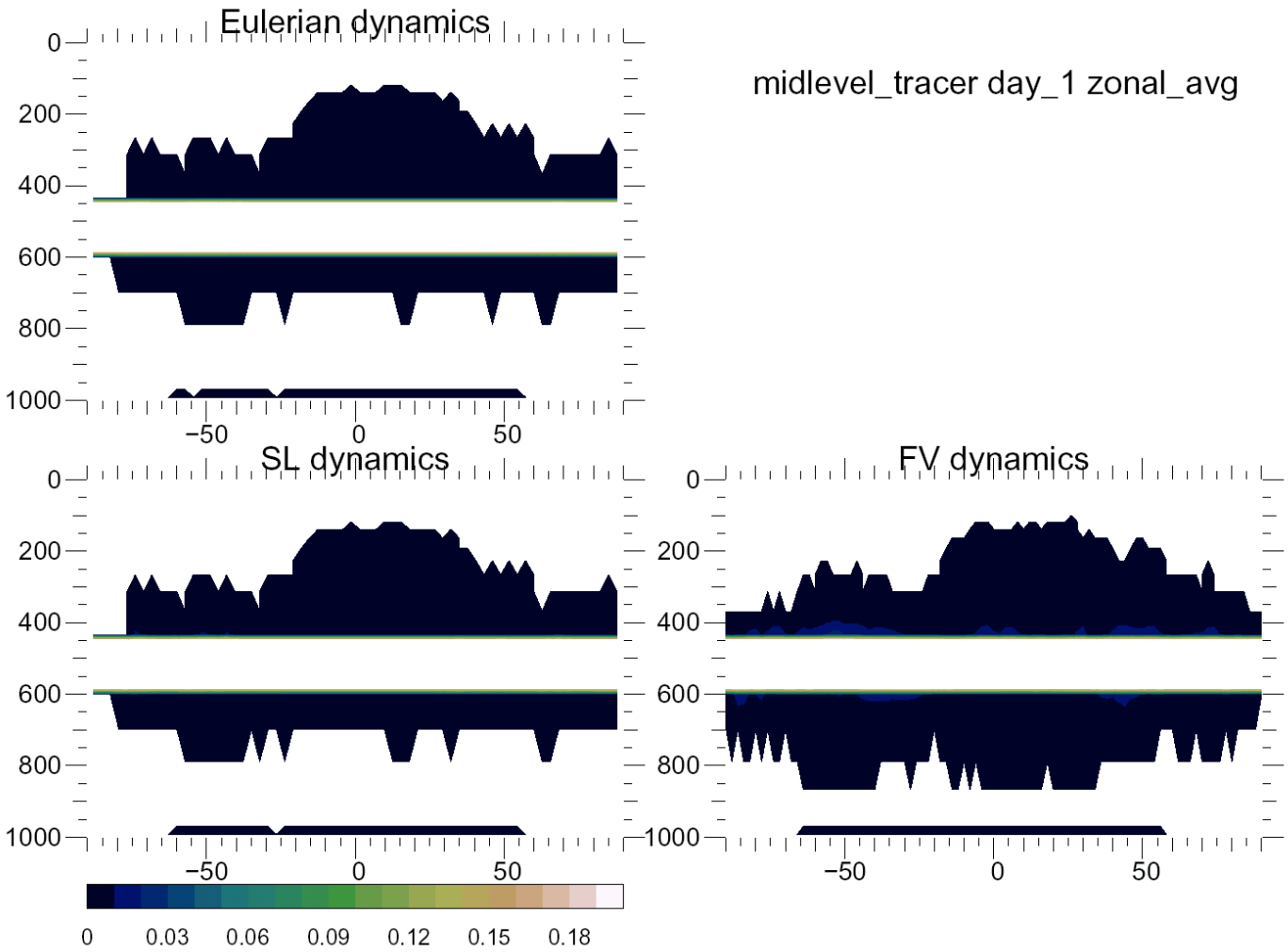
Pseudo-Ozone after 1 year



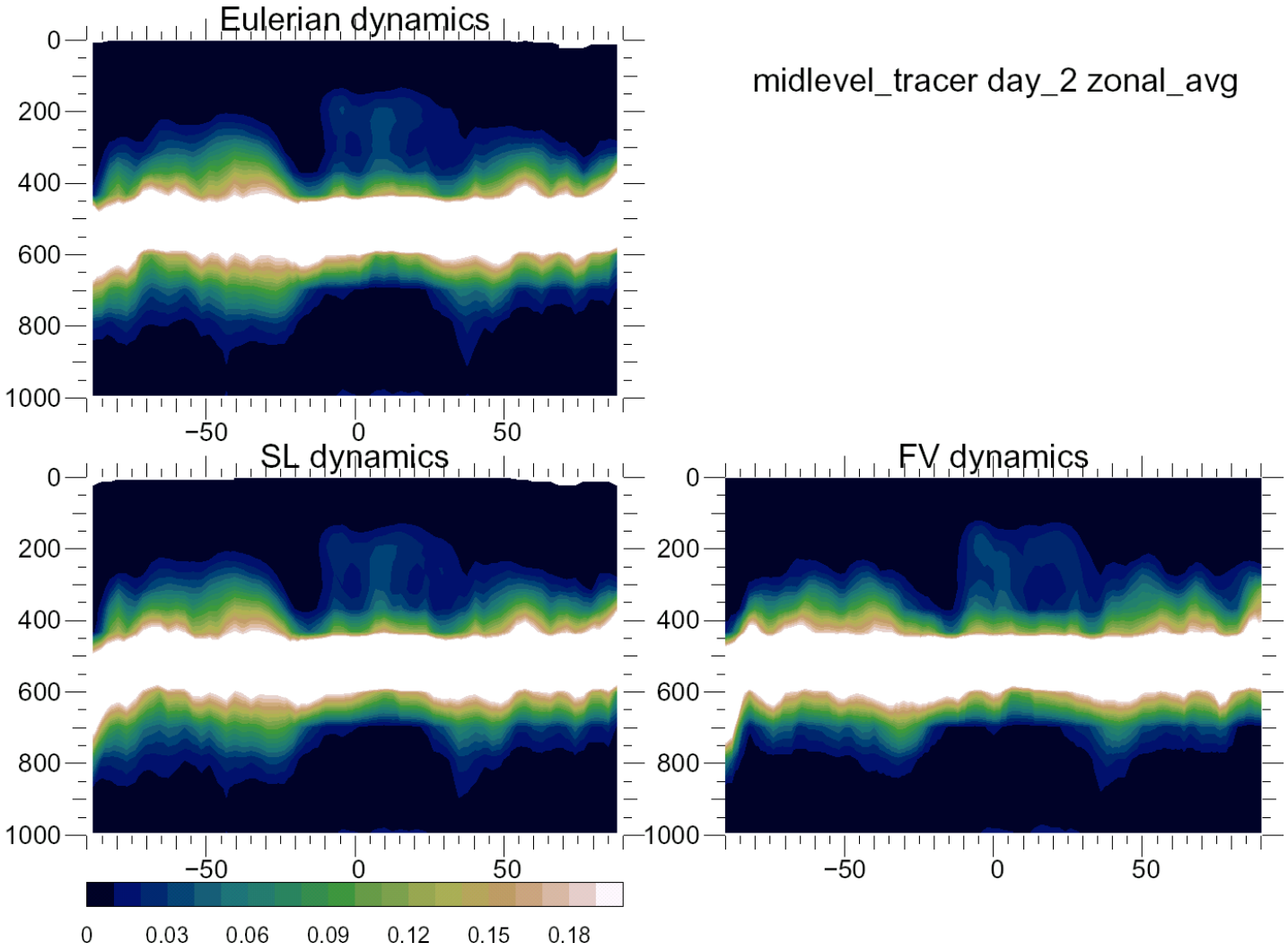
SF6 after 14 months



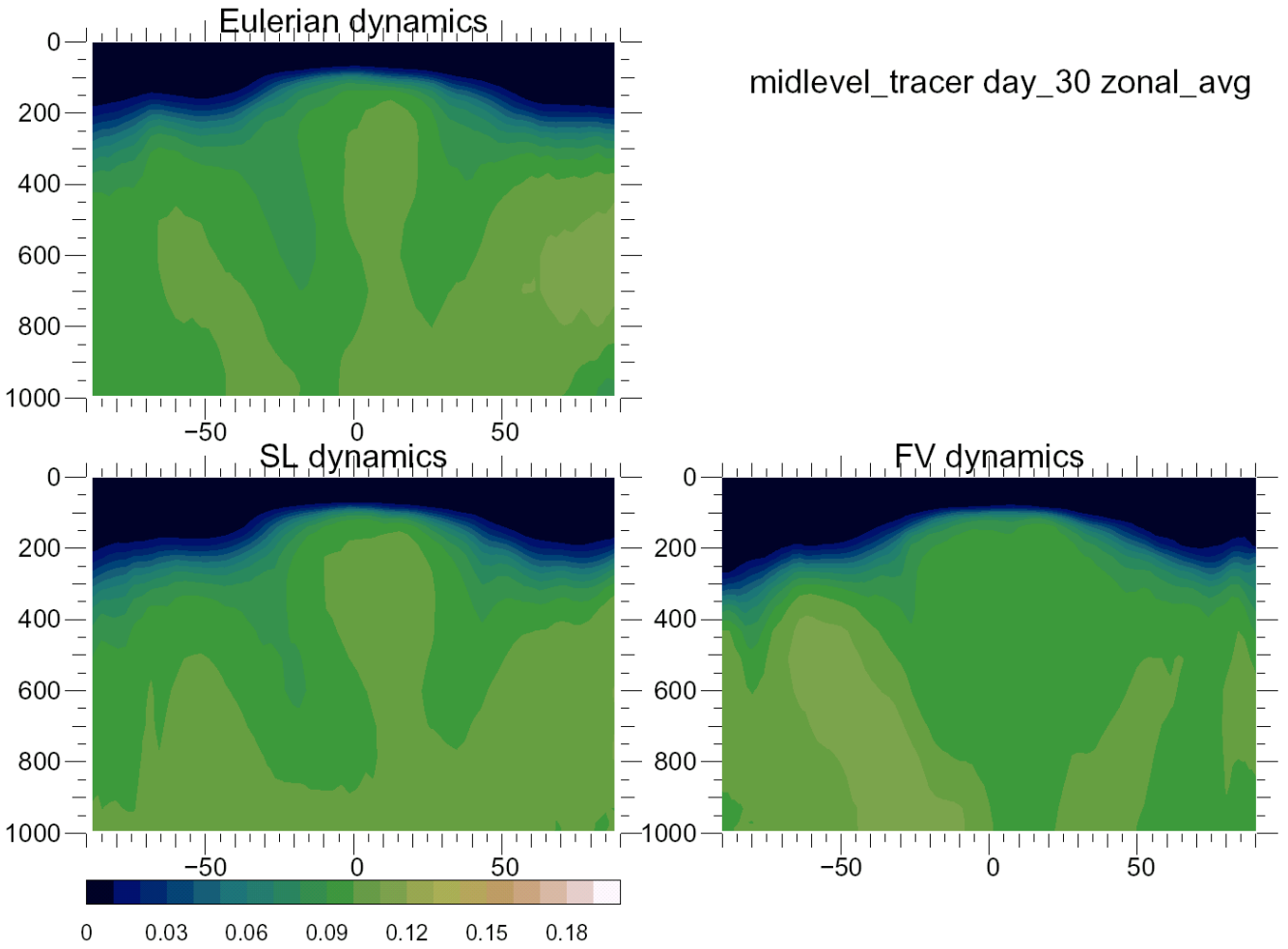
Example Tracer test
Midlevel tracer Day 1



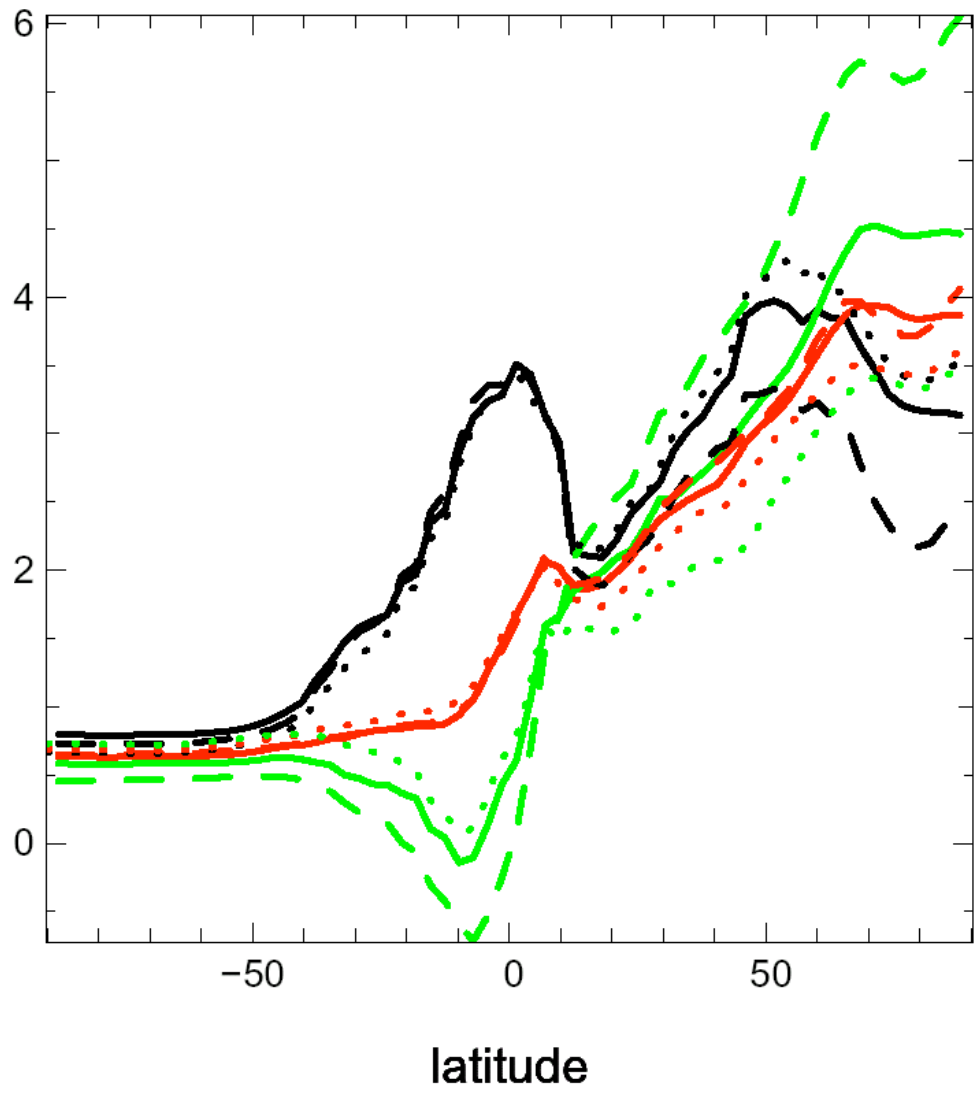
Midlevel tracer -- day 2



Midlevel tracer - Day 30



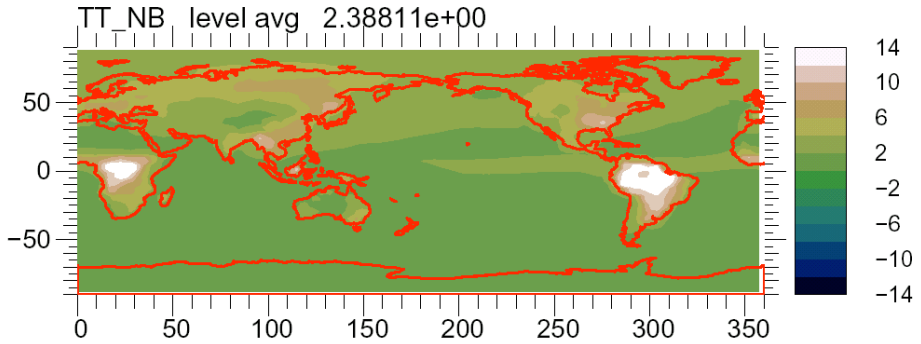
neutral biosphere surface mixing ratio
annual average zonal average



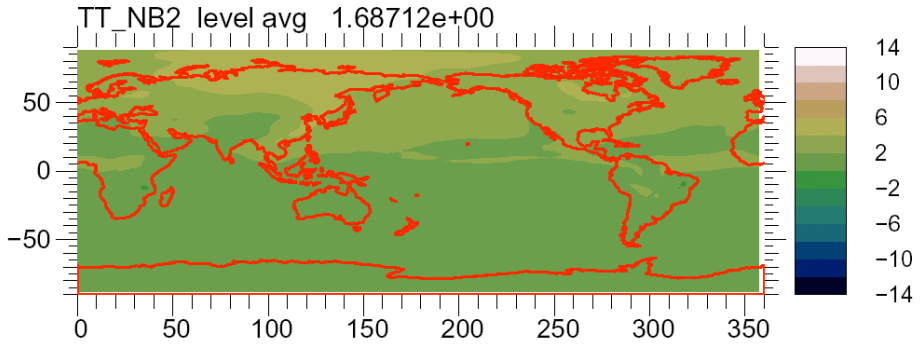
spectral standard diurnal source
spectral monthly mean source
spectral shifted diurnal source
semi−lagrangian standard diurnal source
semi−lagrangian monthly mean source
semi−lagrangian shifted diurnal source
finite volume standard diurnal source
finite volume monthly mean source
finite volume shifted diurnal source

Annual Average Sfc mixing ratio

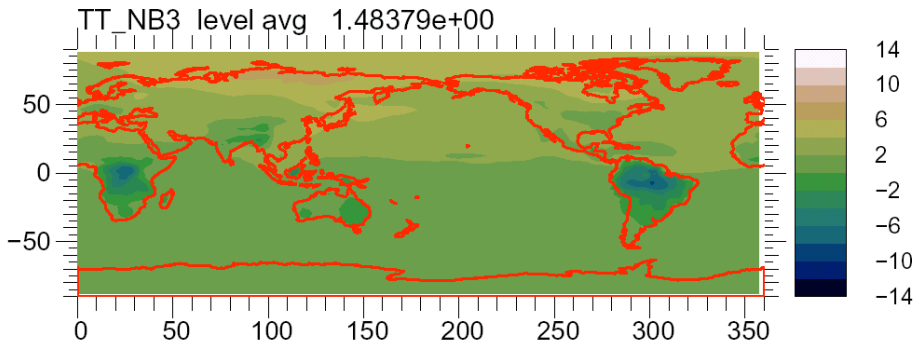
Std diurnal source



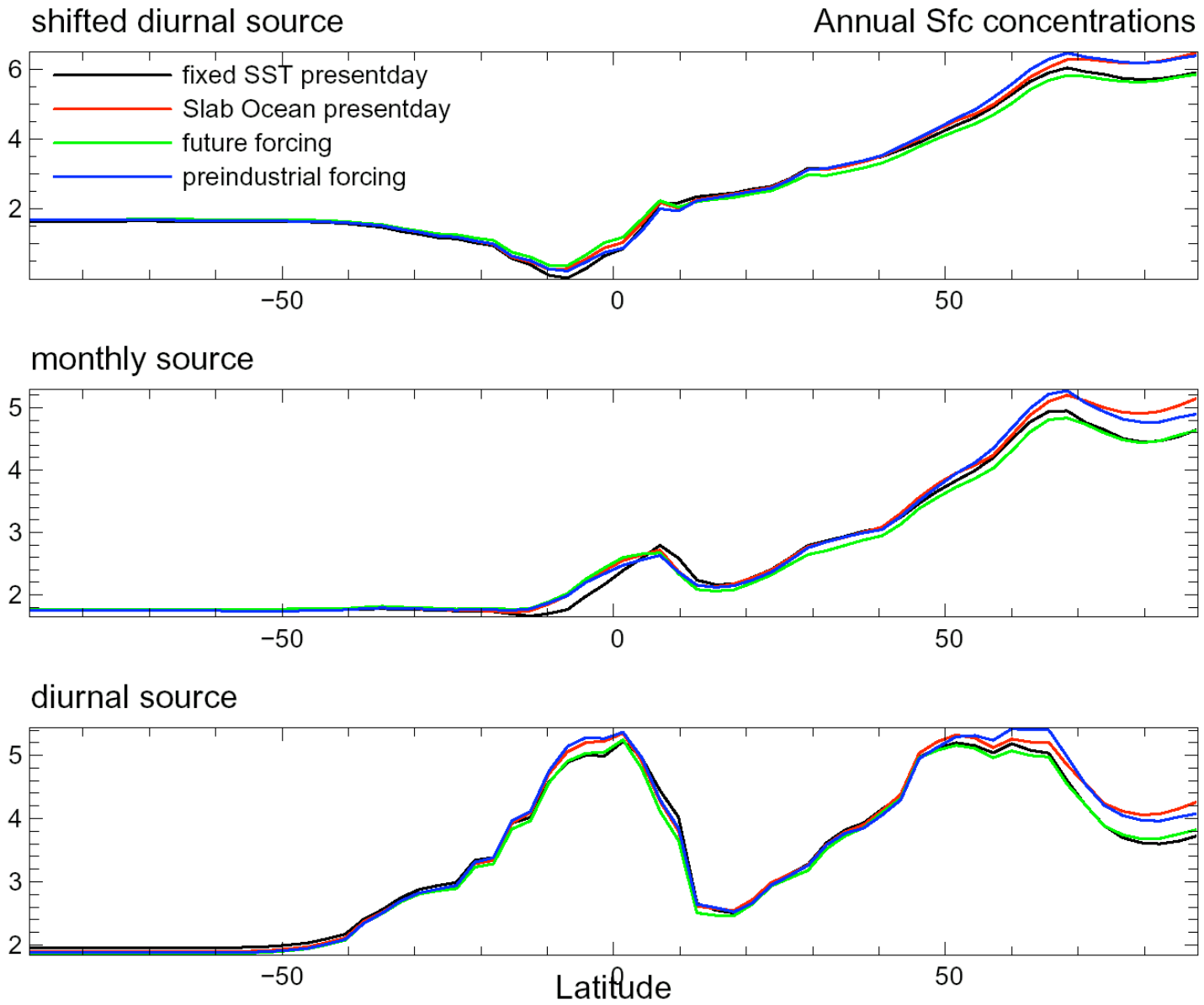
Monthly mean source



Shifted diurnal source



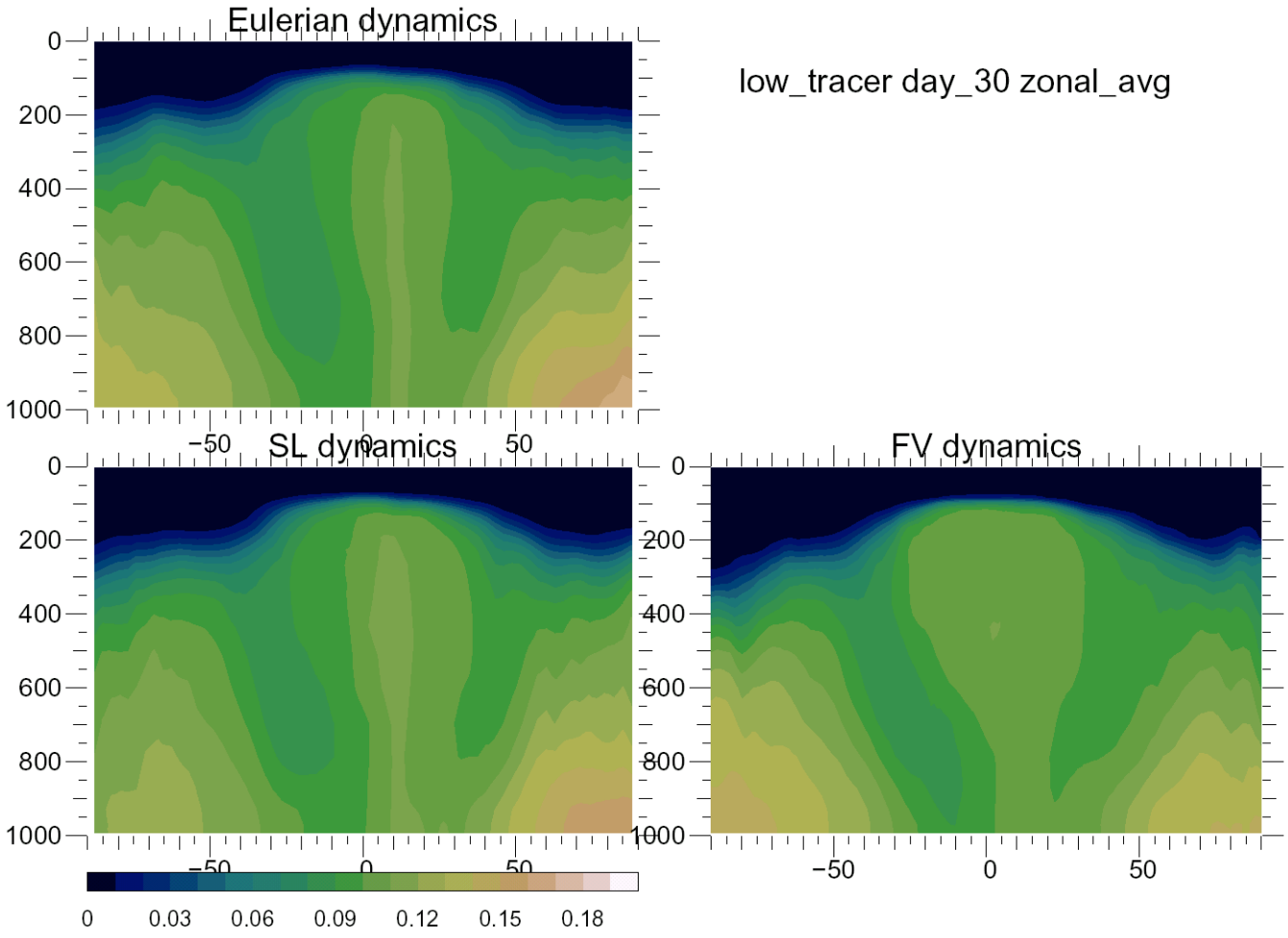
Response to changes in forcing



Summary

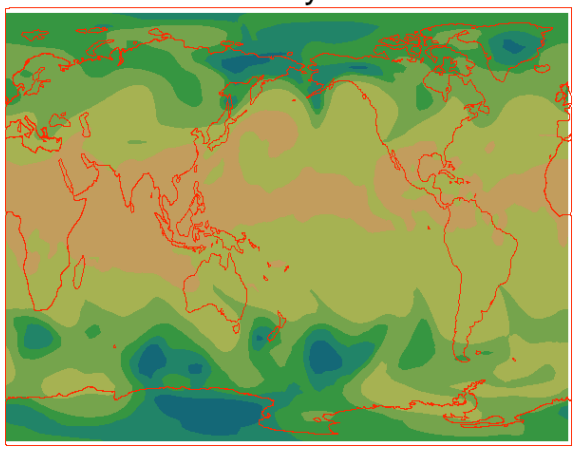
- Rectification is very sensitive to numerics and phase of rapid transport processes (convection and PBL)
- Tracer is not so sensitive to changes in GG and aerosol forcing when vegetation is not dynamic.

Low level tracer, day 30



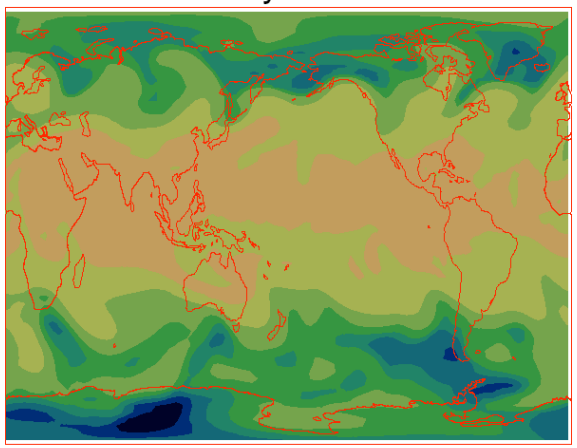
Low level tracer at 200mb day 30

Eulerian dynamics

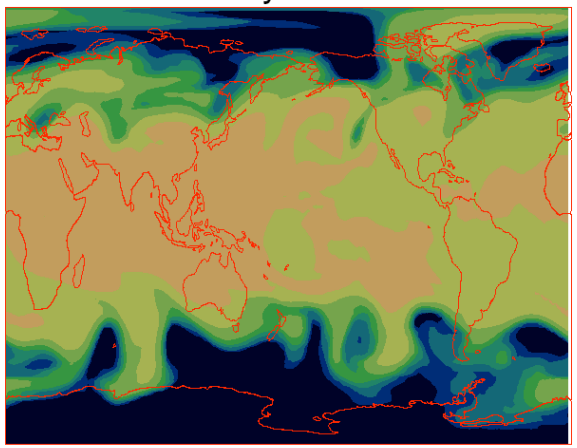


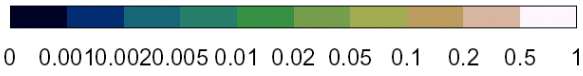
low_tracer day_30 200_mb

SL dynamics

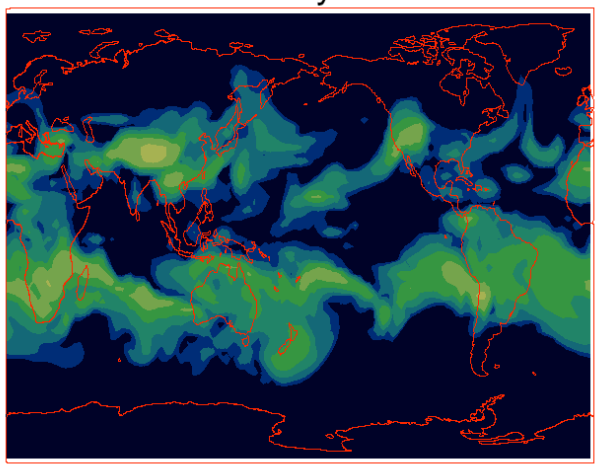


FV dynamics



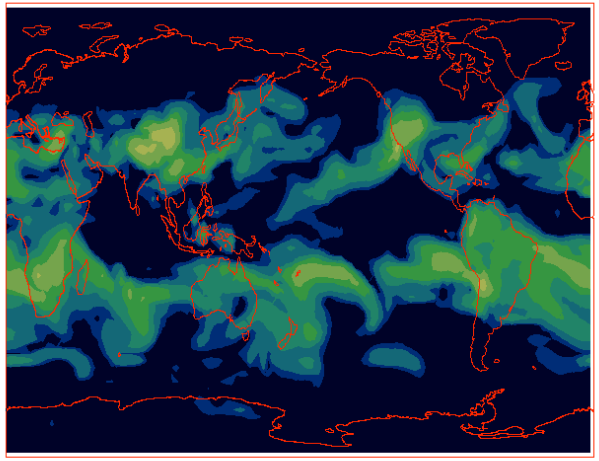


Eulerian dynamics

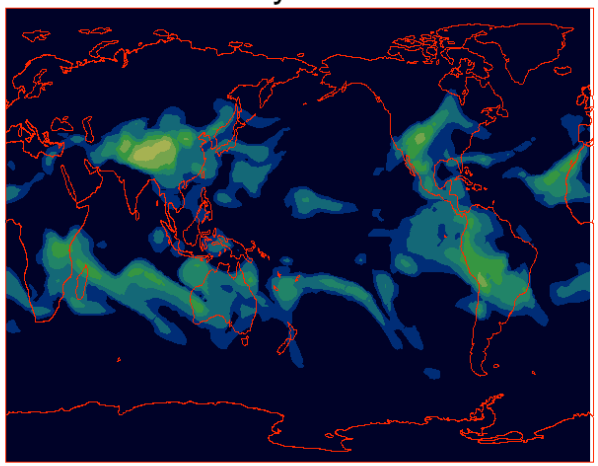


high tracer, day 10, 800 mb

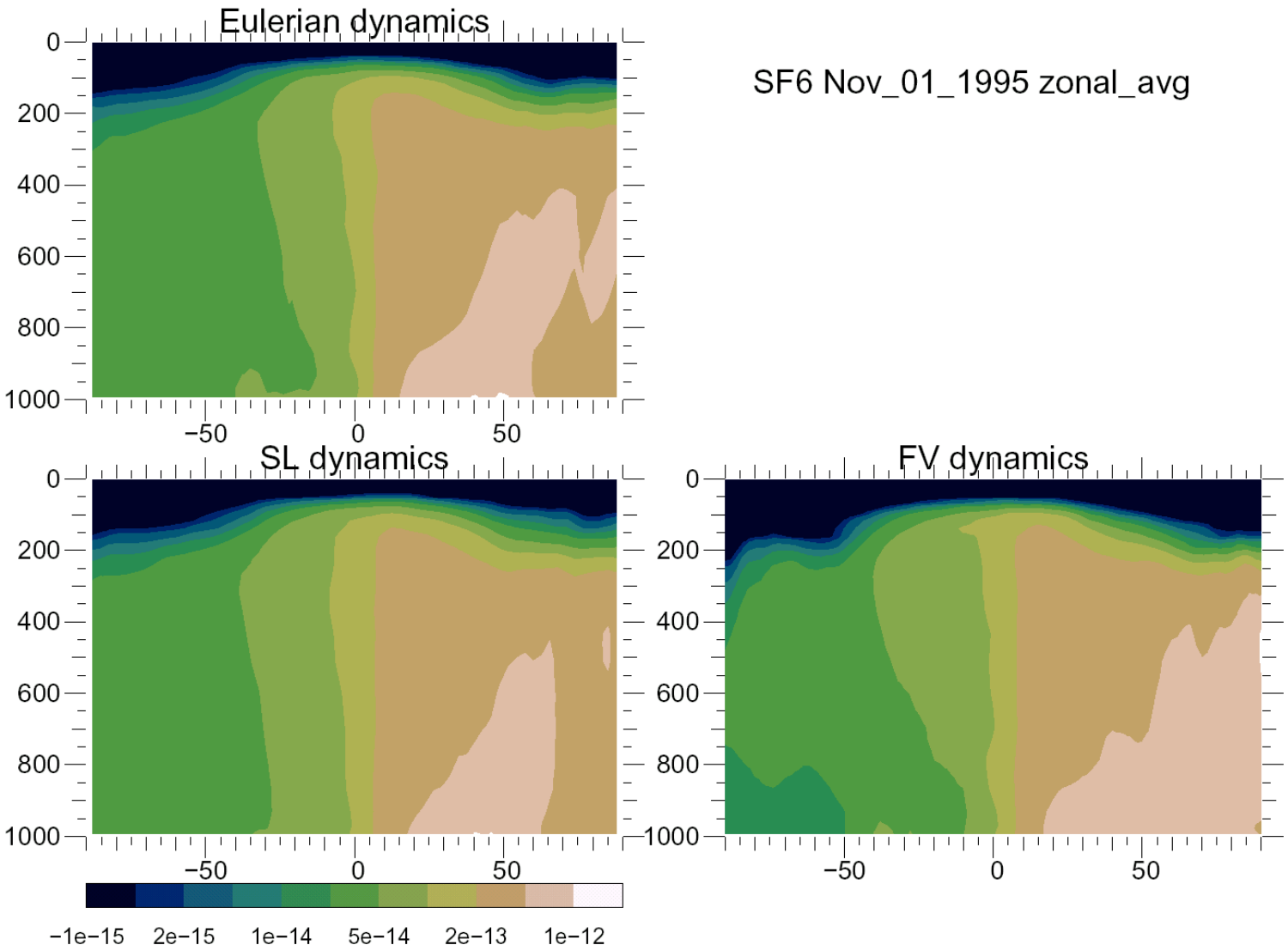
SL dynamics



FV dynamics



SF6 after 60 days



Importance of transport in CSM

- Currently:
  - (3 water species, heat, momentum)
- Frequent need for other species
  - Aerosols and precursors
  - Chemical species (WACCM, tropospheric mechanism)
  - Carbon Cycle
  - Isotopes
  - Tagged species (regions, processes)

Transport of species

- A function of
  - Dynamics
  - Physical processes
    - Chemistry
    - Convection
    - Scavenging
    - Turbulent transport
  - Numerical Artifacts

Computational Artifacts

- CAM works most naturally in terms of a "moist mixing ratio"
  - mass tracer/(mass dry air + mass of water vapor)
  - Consequently mixing ratio of all tracers should change if water vapor changes
- Lack of consistency in transport across processes!
  - Conservation
  - Preservation of a constant
  - Overshoot/Undershoot (monotonicity)

Transport(tracerA)+transport(tracerB)=Transport(tracerA+tracerB)

Revised CAM transport

- Dry mixing ratio across physical processes.
- SLD and Eulerian models use dry mixing ratio. FV uses moist mixing ratio.
- Revised conversion to/from moist and dry mixing ratios.
- Improved fixer for Eulerian and semi-Lagrangian dynamical cores.

Remaining Problems

- A number of processes assume positive tracers
- Convection treats water vapor and heat differently from all other species (no flux limiting). Other species use a "positive definite", but not "monotonic" scheme.
- Nonlinearity of transport is detectable. How good is "good enough"?